

## ENGINEERING AMERICA'S ENERGY FUTURE ( rev 2)

Eric B. Forsyth

**Introduction.**

Within the next generation two problems of global proportions threaten the way of life as we now know it in the United States. They are:

1. Global Climate Change.
2. Global depletion of fossil fuel.

They are related; most scientists agree that the release of carbon into the atmosphere by the burning of fossil fuel in the past century has contributed in some degree to the present warming trend. What is more contentious is how much change will be produced in the future by burning the remaining reserves of fossil fuel, the true extent of which no one really knows. If the human record with timber and fish is any guide, it has to be assumed that eventually all fossil fuel left on the planet will be consumed and the trapped molecular carbon entombed over millions of years will be released over a period measured in decades. If that is the case, the only countervailing strategies now in place are: a) ineffective control of the rate of consumption using carbon credits and mostly voluntary conservation, and b) capture of the carbon in quite expensive ways on a small scale. It is hard to believe that these measures will have a significant effect, but I hope I am wrong.

Many experts believe that global oil production has peaked; this means that supply cannot be significantly increased to meet rising demand from populous developing countries such as China and India. At present the US is the largest consumer of oil, thus increased competition for the remaining reserves will have a severe impact on this country. A strategy the US could adopt which would simultaneously address both these crises is to *develop alternative energy sources* which do not depend on fossil fuel. This is an immense problem; the infrastructure that provides our energy needs from transportation fuels to electricity is enormously complex and cost uncountable billions over many decades, as will an alternative. In the US a shortage of energy during the next generation is far more likely to cause social disruption than the effects of climate change.

Conservation is an important element on the road to alternative energy sources. By developing energy efficient technologies we reduce the load that will eventually be supplied by alternative sources. It has been suggested that conservation will extend the life of the reserves and thus provide more time for the development of alternative technologies. This may not be true; conservation in the US will probably be offset on a

world-wide basis by increased demand from other countries and population growth. But conservation could reduce imports, although to be strictly logical and ignoring economic and diplomatic implications, it may be preferable to consume oil and gas from other countries and conserve domestic reserves. In recent years hybrid cars have made some penetration into the automobile market. This is a good example of conservation; a more efficient machine to do the same task. Other technologies have also appeared such as cars powered by fuel cells using hydrogen and all-electric cars using batteries, which is how very early autos were powered. Whether or not they conserve fossil fuel depends on where the hydrogen or electricity for charging comes from. Using ethanol as a fuel is discussed below. Conservation only saves energy, certainly a good thing, but it does not provide an alternative to support our present life style. I must emphasize; conservation is not the same as an alternative source.

### **Alternative forms of energy.**

Two properties of the major fossil fuels; oil, natural gas and coal, will make it very difficult to find 'plug-in' substitutes. These are:

1. They are transportable and pack high energy content per unit volume.
2. The energy is inherent; it was generated by Mother Nature millions of years ago and stored until Man exploited it.

A significant fraction of the fossil fuel consumed in the US, about a third, is converted to electricity. Our society has become completely dependent on the reliable, stable delivery of electric power. Several proposed alternative sources of energy would also generate electricity, to be a viable alternative the electric power generated this way must meet the same quality standards as the present system. This may limit the contribution they can supply because of the nature of the electricity network; at any moment the power generated and the power consumed are matched, there is virtually no storage of electrical energy. In the future, increased use may be made of electric power to displace fossil fuel in such applications as space heating, rail transportation and even all-electric automobiles. If this occurs, besides many more generating plants, the transmission and distribution networks must be greatly expanded, including a national transmission grid. Such a strategy matches the massive urbanization of the population that has occurred since WWII by concentrating load centers.

### **Renewable Energy.**

At present by far the most important renewable energy resource is hydro-electricity. Most of the power generated this way comes from agencies such as the Tennessee Valley Authority and the Bonneville Power Authority in the west which control massive dams. Unfortunately most of the suitable sites in the US have already been developed and further expansion would be difficult. There may be opportunity to develop 'low-head' hydro, but on the scale power is needed this would be a small contribution. The large hydro installations in the US have an attribute that is not

provided by many other proposed renewable sources; the power is available continuously, day and night, rain or shine. Only a long period of severe drought can compromise operations.

In the past decade or so, two renewable but intermittent sources of energy have been widely promoted; wind turbines and photovoltaic generators. Both provide electric power, but because the basic source of energy, wind and sunlight, are not fully under control of the operators the power does not meet the quality standards of the present system. The intermittent characteristic of wind power can be gauged from experience in Europe where power supplied by wind generators to the grid averaged over a year is about 25% of the maximum rating of the wind turbines. They can only be used if connected to a large grid so that the intermittent characteristic can be backed up by power drawn from other generators operating off fossil fuel, nuclear or hydro primary sources, that is to say, a kilowatt of wind power requires a matching kilowatt of conventional generation somewhere in the system. There are also stability problems associated with connecting a myriad, widely dispersed, relatively small generators to a network if their total power begins to approach the network capacity, although advanced computer control systems incorporating weather data may be able to ameliorate the problem. An aspect also observed in Europe, where there is more wind-generated power connected to the grid, is that back-up energy sources must be capable of fast start-up, perhaps gas turbines, to match the rapid changes in wind velocity or incident sunlight that can occur. In any power system the demand fluctuates by day and by season, but there is a load consumption below which demand never falls, known as the base load. Typically the base load is 40% of the peak load. System operators usually supply the base load from nuclear or large coal-fired plants so that their output remains essentially constant. Obviously the degree of penetration into a power system by intermittent sources could never be allowed to approach the base load. Many of these drawbacks also apply to other ideas under review such as tidal and wave generators and solar steam boilers, even designs with limited (diurnal) energy storage. These constraints mean that such sources must be regarded as a form of conservation, possibly quite useful and able to make a contribution, but not a genuine alternative.

Another renewable source which has been heavily subsidized to bring it to market is biomass. Of course, in centuries past, wood was mankind's most common source of heating, but the goal of modern biomass production is to replace fossil fuel with ethanol, obtained by fermentation or with oil from plants. In Brazil a national effort has resulted in significant displacement of gasoline for autos using sugar cane as the feedstock. The US, much further north with less solar radiation, has embarked on a similar program using corn as the feedstock with less success. The energy available from the final product is not much different than the energy invested in its production. On the downside is the loss of agricultural land for food and the water needed for irrigation. Even with a vast electrification program, many energy users would still need

portable fuel sources, for example; remote habitation, heavy trucks, farm and construction equipment, planes and ships. These markets could support a large bio-fuel industry. The carbon released on burning bio-fuel is presumably drawn from the soil, fertilizer and the atmosphere during growing and does not represent 'old' carbon.

### Non-Fossil Primary Energy Sources.

'Primary' means the power is available on a continuous basis and can be closely controlled. In a few areas of the US the hot magma of the earth's core is close enough to the surface to provide steam for turbines. In Iceland most of the energy consumed by the relatively small population is derived from this source, the opportunity to exploit sites in the US on the scale needed for significant contribution to national energy needs is much more limited. Apart from hydro, referred to earlier, the largest provider of non-fossil energy is fission of uranium. Nuclear power plants have been operating very successfully in the US for more than thirty years. Some, in fact, are reaching the end of their design life, it must be stressed they have operated reliably and safely despite a lingering public perception that they are dangerous. Just as fossil energy represents the power produced by the sun millions of years ago, fission energy originated in the heart of stars billions of years ago. Current reactor designs, called 'thermal' reactors, are not very efficient at extracting the energy in the nucleus; when the fuel becomes unusable more than 99% of the possible energy is still locked in the waste. Therein lies the problem; safe disposal of such radioactive waste is difficult and highly contentious. The reserves of economically available uranium for thermal reactors will probably not greatly outlast fossil fuel reserves. A few trial reactors have been constructed throughout the world that mitigate these problems. Known as breeders or recyclers they use a different fission mode than thermal reactors by producing plutonium faster than it is consumed. After separation the plutonium can be re-used. Much more of the available energy in the uranium nucleus is extracted and waste volume is greatly reduced because breeders 'burn' the residual waste of thermal reactors. Probably the final residual waste will need to be safely secreted only for centuries, not millennia, because it will be much less radioactive. Make no mistake; plutonium is a highly toxic material that presents severe technical challenges to design ways of separating and re-using it in a breeder. In addition, in a very pure form plutonium can be used to make bombs, which raises serious foreign policy issues when other countries pursue the same path, as they are doing. The complete processing cycle would require the highest level of security and environmental vigilance. To embark on this Faustian compact is a choice forced onto us by our excessive consumption of energy and little sign that our society is prepared to live with a good deal less. Uranium reserves to operate breeders would last for centuries. Finally turning to fusion reactors, these will fuse hydrogen nuclei into helium and release energy in the process. Despite decades of research a continuous fusion reaction has not yet been achieved. Even if this finally occurs on an experimental basis the design of a power plant would require much more

development. This source of primary energy is many years away from practical realization, but may represent hope for future generations.

### **A National Strategy.**

It is impossible to predict the future, but a strategy can be formulated based on events which are highly likely to occur. It is very likely that oil and natural gas production will not rise significantly in the future and increased demand for these products will force up the cost. Eventually demand will seriously outstrip production and unless alternative energy sources and infrastructure are in place by then there will be major disruptions of our way of life. This scenario will not occur overnight, but construction of alternative energy sources using existing technology must start immediately, these can then be phased in as oil and gas reserves fade away. Coal, which could provide electric power for over a century, albeit with high carbon emission might well represent the final gasp of fossil fuel energy production for our grandchildren. There is some irony in this as coal kicked off the industrial revolution and started mankind on the profligate use of energy.

#### **National priorities.**

Before listing the technical options which must be pursued there are two issues which have to be resolved and are outside the scope of this position paper:

1. The ordering of national priorities. Even the US has a finite budget. A balance must be achieved to use our financial, intellectual and material resources to preserve national defense, start the construction of alternative energy sources and greatly expand R&D in this field. I suspect that to implement all the recommendations in this article the annual expenditures would be comparable to the current defense budget using both public and private funds. At the same time our commitment to existing social services such as medical care, social security and welfare will have to be maintained.

2. Plan and implement a National Alternative Energy Program. This organization must coordinate private and public spending on a huge scale regardless of short-term energy cost fluctuations; it must have plenipotentiary authority not seen since WWII. Individuals and corporations are motivated by self interest; the organization must ensure private self interest is not in conflict with the national goal, that is, the lobbyists must be kept at bay. A realistic assessment of remaining fossil fuel reserves must be prepared in conjunction with a plan for timely introduction of alternative sources.

#### **A Plan of Immediate Action:**

- Embark on a massive public education program so that citizens can understand the need for drastic measures.

- Promote all measures possible to foster conservation, for example, higher automobile gas mileage limits, expanded public transportation, electrification of railroads and electrification of space heating.
- Massively expand the electric power system using nuclear reactors. Build a national electrical transmission grid, as the system grows it will be able to accept more power from renewable sources.
- Start the immediate development on an urgent basis of thermal reactors, breeder reactors, and reprocessing plants combined at a single site to serve as a demonstration for the future path.
- Re-evaluate the ethanol program, and investigate the use of more productive feedstocks.
- Develop new hydroelectric sites, possibly in cooperation with Canada.
- Increase funding for energy R&D, for example breeder reactors, fusion power plants, hydrogen production from renewable sources, electric automobiles, improved photovoltaic panels, extending the storage time of solar thermal, etc.
- Develop cost effective methods of CO<sub>2</sub> sequestration so that coal can continue to be used for power production without serious environmental impact. Set carbon limits for both the national use of coal and its use if exported.

### **Final Thoughts.**

The era of cheap energy is ending. It brought the population of the USA, and many other countries, a standard of living never before seen in history. With clear thinking, a national will, and lots of money we can overcome our addiction for fossil fuel and build a society that will maintain the way of life we have come to regard as normal. If we don't, our children will look back on the last hundred years as a golden age. I find on discussing this problem with members of the general public that there is complete disbelief that the problem exists. There always seems to be a tendency to believe reserves are bigger than they are. This is rather like what happened to the Atlantic cod; for decades fishermen, governments and the public believed (or pretended to) that the cod supply was inexhaustible, and then the stocks collapsed to zero. When pressed about where the oil will come from in the future, people tell me 'they' will fix it. Who are 'they'? They are the engineers, scientists, entrepreneurs, businessmen and the government who must cooperate to ensure the alternatives are in place when the oil companies tell us the 'The well is dry'. The proposal to greatly increase the energy supplied by electricity using nuclear reactors may seem drastic to many, but there is no other technology that can supply the scale of energy needed in a 'clean' manner. I wish there was another solution. The other option is to greatly reduce per capita energy consumption by mandated or voluntary means, increased cost, or shortages; some combination of which may well occur.

I must acknowledge many useful discussions with friends and colleagues, particularly members of the Brookhaven Retired Employees Association. However the opinions expressed are my own.

Eric Forsyth was a member of the scientific staff at Brookhaven National Laboratory for 35 years. He served as Chair of the Accelerator Development Department and manager of the Power Transmission Project. In 2007 he received the Herman Halperin Award from the Institution of Electrical and Electronic Engineers (IEEE) for his research on advanced power transmission systems. Since he retired in 1995 he has sailed his yacht *Fiona* to both Polar Regions to investigate personally the effect of climate change. He has also sailed twice around the world where his observation of social changes in many countries aroused his interest in the future of energy production.